

What Makes Time Tick?

Who put the one-way sign on time? Superstring theorist Brian Greene tries to figure out how the universe's rush from order to chaos gives direction to the fourth dimension.



by **SCOTT DODD**

FQXi Awardee: Brian Greene, Columbia University

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Humans have a flexible relationship with time. In our minds, it seems that time can speed up, slow down, fly when you're having fun, stand still, march on, and heal all wounds.

One thing it can't do, though – outside of our memories and science fiction movies – is go backward. Whether we perceive time sprinting or crawling, it's always heading in the same direction – forward.

In 1927, British astronomer Arthur Eddington coined a term to describe this apparently immutable fact of the cosmos. He called it "time's arrow." It's a property that makes time different from the other three dimensions, which let you go up or down, back and forth, and side to side.

The fourth dimension isn't so forgiving. Einstein showed that time is relative, but it's still all going forward. There's no turning back the clock.

And no one can explain why.

Low entropy is very unlikely. So why did the universe begin in such an unlikely state?

- Brian Greene

Unbreak My Heart

Time is the deepest mystery that physics has," says Brian Greene, a professor at Columbia University and a recent FQXi Awardee. Greene explores the issue of time's arrow in his best-selling 2004 book *The Fabric of the Cosmos*.

Eggs break and splatter, Greene writes. They don't unsplatter. Cars crash. They don't uncrash. People age. They don't get younger – not outside of a plastic surgeon's office, anyway.

"It's such a basic question, you can explain it to a 10-year-old," Greene says. "In space, we can move any which way we want, at will. Yet there's this other dimension to the universe that has an ironclad lock on us. It always drags you in one direction."

At least, that's the way it seems to us humans. Science isn't so sure.

The laws of physics, it turns out, don't recognize Eddington's arrow. There's nothing about the physical principles of our universe that says time can go in only one direction.

In fact, Greene says, the physical equations worked out in exacting detail over the last century display a property known as "time symmetry," meaning they work just as well backward in time as they do forward. From that point of view, there's no reason eggs can't unbreak, fenders can't unbend, and plastic surgeons can't be put out of business.

So why doesn't it happen? Why does time always march on? Why can you take a step back in space, but not in time?

Whither the Arrow?

Greene is launching a new search for answers with colleagues at Columbia. His research team was awarded a \$70,000 grant from The Foundational Questions Institute for a three-year project to study time's arrow.

Don't get the wrong idea. Greene and his collaborators aren't out to change history or discover time travel or anything. What they want to understand, Greene explains, is "Why do events unfold in one temporal order and essentially never in reverse?"

So don't expect any trips back to the Mesozoic out of this one.

Greene is one of the world's leading physicists and a proponent of superstring theory, which posits that the most basic particles of matter are actually composed of ultra-tiny, vibrating strings.

String theory seeks to tie Einstein's laws of space and gravity together with the strange microscopic realities of quantum mechanics. The goal is to create a unified theory of how the universe works.



REVEALING TIME'S ARROW Brian Greene

Greene grew up in New York City as a math prodigy. He majored in physics at Harvard and went to Oxford as a Rhodes Scholar.

His 1999 book, *The Elegant Universe*, explains string theory for a mass audience. It was a finalist for the Pulitzer Prize and became a series on public television's *Nova*, which Greene hosted. He's probably the only physicist in the world to appear on both *The Colbert Report* and *David Letterman*.

To unravel the conundrum of time, Greene and his colleagues plan to re-examine quantum mechanics, Einstein's theory of gravity, and even the origin of the cosmos. Greene calls it "a thought experiment in the language of mathematics."

Obedying the (Second) Law

One of his collaborators, David Albert, is a professor of philosophy at Columbia. Science philosophers, it turns out, have spent a lot of time thinking about some of the issues that Greene believes may be critical to understanding the direction of time.

A number of explanations for time's arrow have been put forth in the past. The most likely culprit, most cosmologists agree, is entropy.

The Second Law of Thermodynamics says that entropy in an isolated system will increase over time. If that isolated system happens to be the entire known universe, the second law suggests that the universe will move from a more ordered state to a less ordered one.

More ordered equals past, less ordered equals future. The result: time's arrow.

What, though, set the second law in motion? Why is the universe fated to go from order to chaos? The explanation, it appears, is that the nascent universe found itself in a highly ordered – and highly unusual – state soon after the Big Bang.

Entropy at the Beginning

Paul Davies, a world-renowned physicist, did pioneering work on time in the 1970s. (His latest book is *How To Build a Time Machine*.) He says that cosmologists can actually see this highly ordered state, in a thermal map of the sky taken from satellites. The map shows the cosmos just 380,000 years after its birth as a mass of hot gas spread evenly throughout the universe, one section indistinguishable from another.

During the 14 billion years since, the force of gravity has taken over, pulling that once-uniform matter into clumps that become stars and galaxies and nebulae and black holes. All of this happened as the cosmos has been racing to get back to its natural state: utter chaos.

But if entropy is the answer, that still doesn't solve the puzzle.

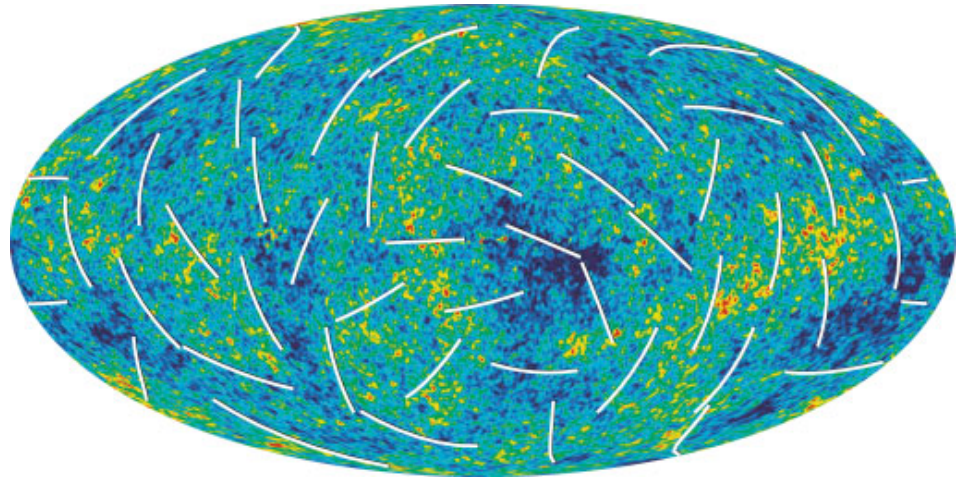
"If we agree it has to do with entropy," Davies says, "the question remains, how did the universe get itself into that state in the first place? The last word certainly has not been said on the subject."

Total order, after all, is a pretty strange thing, as anyone who has ever run an office or a household can tell you.

"Low entropy is very unlikely," Greene says. "So why did the universe begin in such an unlikely state? That's what we're trying to show."

Greene says he finds the question of time fascinating, especially because it relates to so many other areas of physics. He hopes that exploring how time works will lead to profound insights about the nature of reality.

"That," he says, "would be a wonderful outcome."



YOU ARE HERE The COBE Map. Photo Credit: NASA/WMAP Science Team

Mapping the Big Bang

In 2006, two guys won the Nobel Prize in physics for making a map. Not just any map, though – otherwise the atlas-making folks over at Rand McNally would start to wonder where *their* prize is.

This Nobel-winning map looks back at the early days of the universe, just 300,000 years or so after the Big Bang. It's been called the first baby picture of the cosmos.

The story of this map goes back decades. In the 1960s, two other Nobel Prize winners – Arno Penzias and Robert Wilson at the Bell Labs in New Jersey – observed a phenomenon known as the Cosmic Microwave Background Radiation (CMB). (It took a while to understand what they had detected. At one point, they thought the signal might have come from pigeon droppings splattered on their sensitive microwave antenna.)

As Penzias and Wilson found, the CMB's electromagnetic signal spreads out evenly across the sky, telling cosmologists that the early universe must have been composed of a fairly uniform mass of hot gas. (That revelation leads to the order-to-chaos theory of time's arrow.)

It didn't make sense that the early universe would be *perfectly* smooth, though: what would have led to the formation of everything that surrounds us today? A perfectly even universe would have stayed spread out and boring forever, since there would be nothing on which gravity could work its accreting magic.

So, cosmologists suspected that the CMB must include minor variations that would let gravity take effect, pulling the spread-out hot gases into clumps that would eventually become stars and nebulae and galaxies and all the other forms of matter we know and love.

In November 1989, NASA launched the Cosmic Background Explorer satellite, known as COBE, to look for tiny variations in the temperature and density of the CMB. It didn't take long to get results.

Scientists used computers to meticulously crunch the data from COBE's first year in orbit and unveiled the results at a 1992 meeting of the American Physical Society. The team of more than 1,000 researchers and engineers was led by John Mather of NASA's Goddard Space Flight Center and George Smoot of the Lawrence Berkeley National Laboratory and the University of California, Berkeley.

COBE, they announced, had indeed found tiny variations in the temperature of the CMB – in the range of a hundred-thousandth of a degree – indicating that small patches of the infant universe had contained slightly more matter than the rest of the gas cloud around them.

Those slight variations would have been enough for gravity to slowly sink its claws into the nascent cosmos. Their results received a standing ovation from astronomers.

The COBE scientists used their data – as well as subsequent measurements of the CMB – to create an image of the early cosmos, showing the tiny fluctuations in temperature. The COBE map, as it's now called, shows blobs of cyan and magenta, reflecting the cooler and hotter regions of the sky.

Mather and Smoot's Nobel Prize credits the COBE project with providing increased support for the Big Bang theory and marking "the inception of cosmology as a precise science."

As important as that early image of the universe is, though, it still leaves the question: How did the young cosmos get that way? It's that enduring mystery which a grant from FQXi will help physicist Brian Greene and his colleagues ponder.